Integrated Adaptively Predistorted Analog Optical Transmitter

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Abstract *An integrated photonic transmitter circuit incorporating an adaptive optical predistortion circuit is demonstrated. Simultaneous distortion cancellation of an electroabsorption modulator and driver amplifier allows improvement in dynamic range while using an efficient but nonlinear driver.*

Introduction

Several linearization schemes have been deployed to improve the linearity of optical transmitters. Perhaps the commercially most successful is using a predistortion circuit where improvements in performance can be achieved using an inexpensive power efficient electronic circuit [1]. This approach is typically not adaptive with changing operating conditions and require that the response of the transmitter stays constant. It is therefore not suitable for integration with a widely tunable transmitter and a modulator that has wavelength-dependent response.

An alternative is using feed-forward linearization where the modulated signal is tapped off and compared to the input to form a correcting signal to be added to the output [2]. In this way any variations of the response are automatically corrected. However, the added signal must be separated in wavelength to avoid coherence effects, and is therefore not compatible with a WDM environment.

In this work, a predistortion circuit is constructed by measuring the nonlinearities of a first optical modulator to provide the predistorted input to a second modulator. This approach combines dynamic extraction of non-linear response and WDM compatibility. Past demonstrations of this approach has typically been limited by the need to use two separate transmitters with slightly different response [3]. Here, the two modulators are integrated closely on a single chip, sharing a single optical source. Any variations in chip temperature, input power or wavelength now affects both modulators equally and can be dynamically compensated for.

Experimental arrangement

Figure 1 shows a schematic of the demonstrated predistortion arrangement. The input signal is split in a 2:1 ratio, where the lesser part is used to drive the predistortion link. The output of the link is then subtracted from the remainder of the input signal to form the predistorted input to the second transmitter. A driver amplifier and an optical attenuator are included in the link to ensure that the input power to the two transmitters stays equal for optimum distortion cancellation.

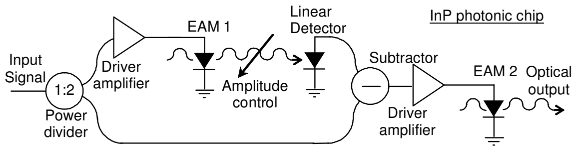

Fig. 1. Operational schematic of broadband linearization scheme.

If the response of the two driver amplifiers is the same, any non-linear response of these are also cancelled in this configuration. In this manner more non-linear, but lower power driver amplifiers can be used. This is a significant advantage, as typical linear amplifiers can easily consume many Watts of supplied power.

Optical device

In this work, all photonic components of the linearized transmitter are integrated on one single InP chip, including the optical source, splitter, modulators, optical attenuator and detector. The integration is achieved using an offset quantum-well material structure where passive sections are defined by selective removal of the quantum wells. The device is based around a widely tunable SGDBR laser – SOA with more than 40 nm tuning range [4]. This type of device with a single EA modulator has previously been shown to generate a 126 $\mathrm{dBHz}^{4/5}$ SFDR [5].

Figure 2 shows a schematic of the integrated photonic circuit. The power from the source is split into two Franz-Keldysh modulators located in close proximity on the chip. The optical 3dB-bandwidth of the modulator is 8 GHz. A second reversed biased section acts as an optical attenuator and the detector then completes the on-chip optical link in one of the two waveguide paths. The second waveguide forms the optical output.

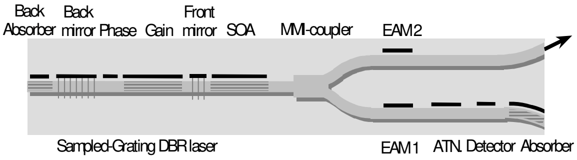

Fig. 2. Schematic of integrated photonic circuit.

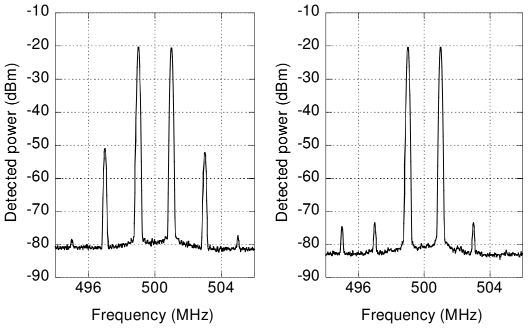

Fig. 3: RF spectra around 500MHz for transmitter with and without predistortion.

Experimental results

The spurious-free dynamic range (SFDR) of the EA modulator without any predistortion or driver amplifier is measured at 98 dBHz$^{2/3}$, when biased at maximum slope. This is about 7 dB lower than devices incorporating a single EA modulator [5], which can be attributed to the lower transmitted power of this particular device. Adding a driver amplifier with low power consumption (~800mW) and low third order intercept point (+15 dBm), the overall link gain is improved at the expense of a penalty in SFDR, now 93 dBHz$^{2/3}$. The left plot of Fig. 3 shows the captured RF spectrum around 500 MHz, where third order intermodulation terms can be clearly observed.

Activating the on-chip predistortion link to compensate for non-linearities, the third-order intermodulation terms can be reduced. The right plot of Fig. 3 shows the captured spectrum where the amplitude and phase response of the predistortion circuit has been carefully matched. More than 20 dB suppression of third order intermodulation terms is observed. This corresponds to a very closely matched phase and amplitude in the summation of signal and predistortion link output. To generate 20 dB of intermodulation suppression, the power must be matched within 0.3dB. The measured SFDR at 500 MHz is compared to the uncompensated case in Fig.4 where a fifth-order intermodulation-limited SFDR of 110 dBHz$^{4/5}$ is obtained, more than compensating for the nonlinearities of the driver amplifier.

To investigate the bandwidth of the predistortion circuit, the center frequency was shifted while keeping all adjustments in the predistortion part constant. The results are shown in Fig. 5 where the dynamic range in a more realistic 1 MHz bandwidth is plotted as a function of frequency offset. 10 MHz frequency offset corresponds to only a 2 dB penalty in SFDR, while the added distortion of the driver amplifier is compensated for within a 50 MHz single-sided bandwidth. This fractional bandwidth can be improved by using more uniform response RF components or an equalizing circuit.

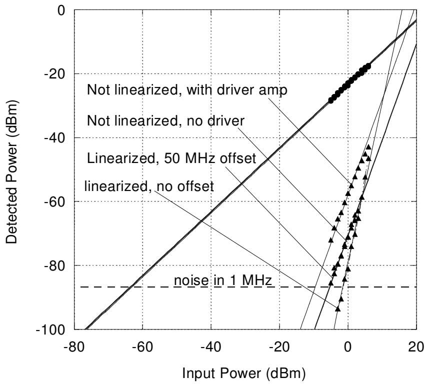

Fig.4: SFDR of the predistorted transmitter with and without 50 MHz frequency offset from setting, and not predistorted with and without driver. The input power has been adjusted to facilitate comparison.

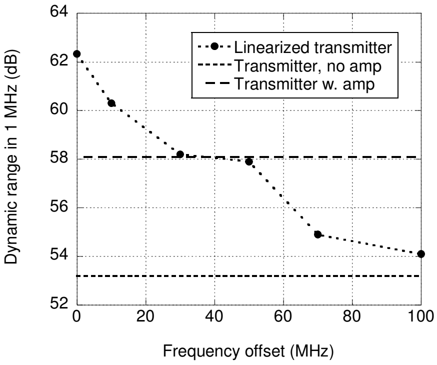

Fig. 5: Measured dynamic range in 1 MHz of the linearized transmitter as a function of shift in operating frequency.

For automatic linearization over the entire tuning range, automatic predistortion gain control will need to be implemented to compensate for the variations in EA slope sensitivity with wavelength.

Summary

We have demonstrated a novel widely-tunable optical transmitter device with an integrated adaptive predistortion circuit based on extraction of nonlinearities using an on-chip optical link. The circuit has not only been showed to compensate for modulator nonlinearities, but also for driver distortion, allowing the use of more power-efficient driver amplifiers. The predistorter compensates for driver amplifier nonlinearities at a 20% fractional bandwidth.

References

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